APPLICATION

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TITLE: MIMO-BASED MULTIUSER OFDM MULTIBAND FOR ULTRA WIDEBAND COMMUNICATIONS

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MIMO-BASED MULTIUSER OFDM MULTIBAND FOR ULTRA WIDEBAND COMMUNICATIONS

Background

This invention is generally relative to a Multiple-Input-Multiple-Output (MIMO)-base multiuser Orthogonal Frequency Division Multiplexing (OFDM) multiband of Ultra Wideband (UWB) Communications for a short-distance wireless broadband communication.

U.S. Federal Communications Commission (FCC) released a revision of Part 15 of Commission's rules regarding UWB transmission systems to permit the marketing and operation of certain types of new products incorporating UWB technology on April 22, 2002. With appropriate technologies, UWB device can operate using spectrum occupied by existing radio service without causing interference, thereby permitting scare spectrum resources to be used more efficiently. UWB technology offers significant benefits for Government, public safety, businesses and consumers under an unlicensed basis of operation spectrum.

In general, FCC is adapting unwanted emission limits for an UWB communication device that is significantly more stringent than those imposed on other Part 15 devices. For the indoor UWB operation, FCC provides a wide variety of UWB communication devices, such as high-speed home and business networking devices under Part 15 of the Commission's rules subject to certain frequency and power

limitations. Limiting frequency bands of certain UWB products, which is based on -10 dBm bandwidth of UWB emission for the indoor UWB operation, will be permitted to operate. The UWB communication devices must operate in the frequency band ranges from 3.1 GHz to 10.6 GHz. UWB communication devices should also satisfy the Part 15.209 limit for the frequency band below 960 MHz and must meet the FCC's emission masks for the frequency band above 960 MHz.

For the indoor UWB communication devices, Table 1 lists the FCC restriction of the emission masks (dBm) along with the frequencies (GHz).

Table 1

Frequency (MHz)	EIRP (dBm)
0-960	-41.3
960-1610	-75.3
1610-1990	-53.3
1990-3100	-51.3
3100-10600	-41.3
Above 10600	-51.3

FCC also defines the UWB communication devices as any devices where the fractional bandwidth is greater than 0.25 based on the formula as follows,

$$FB = 2\left(\frac{f_H - f_L}{f_H + f_L}\right), \qquad (1)$$

where f_H is the upper frequency of -10 dBm emission points, and f_L is the lower frequency of -10 dBm emission points.

The center frequency F_c of UWB transmission is defined as the average of the upper and lower -10 dBm points as follows:

$$F_C = \frac{f_H - f_L}{2}. \qquad (2)$$

In addition, a minimum frequency bandwidth of 500 MHz must be used for the indoor UWB devices regardless of center frequencies.

In the indoor environments, UWB communication devices can be used for wireless broadband communications within a short-distance range, particularly for a very high-speed data transmission suitable for broadband access to networks.

If the 7.5 GHz UWB frequency ranges from 3.1 GHz to 10.6 GHz is used as a single frequency band, an analog-to-digital (A/D) converter and a digital-to-analog (D/A) converter must operate at a very-high sampling frequency rate F_s so that UWB communication transceiver can be implemented in a digital domain. However, this leads to a very-high requirement for the A/D and D/A converters in the UWB transmitter and receiver. Presently, developing such a very high-speed A/D and D/A converter may not be possible with a reasonable cost, thereby having a difficult problem to apply the A/D and the D/A converter for an UWB

communication transceiver based on single frequency band. On the other hand, a single frequency band-based UWB communication transceiver may not have flexibility and scalability for transmitting and receiving a user data. In addition, the single frequency band-based UWB communication transceiver may have an interference with a WLAN 802.11a transceiver without using a special filter system since the WLAN 802.11a operates at a lower U-NII frequency range from 5.15 GHz to 5.35 GHz and at an upper U-NII upper frequency range from 5.725 GHz to 5.825 GHz.

Furthermore, since FCC is adapting unwanted emission limits for an indoor UWB communication device that is significantly more stringent than those imposed on other Part 15 devices as shown in Table 1, the transmitting distance of the indoor UWB communication devices is very limited if employing a convention approach, such as a single antenna in UWB communication devices. As a result, it is expected that transmitting distance is approximately in a range of one meter to ten meters depending on transmitting data rate.

An OFDM is an orthogonal multicarrier modulation technique that has been extensively used in a digital audio and video broadcasting, and the wireless LAN 802.11a. The OFDM has its capability of multifold increasing symbol duration. With increasing the number of subcarriers, the frequency selectivity of a channel may be reduced so that

each subcarrier experiences flat fading. With such advantages, the OFDM approach has been shown in a particular useful for the wireless broadband communication over fading channels.

A direct sequence spread spectrum (DSSS) is to use a pseudorandom (PN) sequence to spread a user signal. The PN sequence is an ordered stream of binary ones and zeros referred to as chips rather than bits. The DSSS can be used to separate signals coming from multiuser. The multiple access interference (MAI) among multiuser can be avoided if a set of PN sequences is designed with as low crosscorrelation as possible.

A MIMO is a multiple-input-multiple-output as a wireless link and is also a space-time signal processing that a natural dimensional of transmitting data is complemented with a spatial dimension inherent in the use of multiple spatially distributed antennas. In addition, the MIMO is able to turn multipath propagation into a benefit for a user. In the MIMO system, signals on the transmit antennas at one-end and the receiver antennas at the other-end are integrated in such a way that the quality of bit error rate (BER) or the data rate of the communication for each user or the transmitting distance is improved, thereby improving a communication network's quality of service.

The MIMO-based multiuser OFDM multiband for UWB communication transceiver system is disclosed herein according to some embodiments of the present invention. The present invention uses eleven frequency bands as a multiband, each of the frequency bands having 650 MHz frequency bandwidths. Each of multi-frequency bands employs an OFDM modulation for a multiuser UWB communication transceiver. A base station of the UWB communication employs eleven antennas while a mobile station of the UWB communication uses two antennas. The solution of the MIMO-based OFDM multiband allows using a set of low-speed A/D and D/A converters in parallel. A unique of PN sequences is assigned to each user so that multiuser can share the same multiband to transmit and to receive information data. An orthogonal sequence is also used to spread the data within each of the multi-frequency band, thereby leading to multiband orthogonality. On the other hand, since the OFDM is an orthogonal multicarrier modulation, subcarriers within each of the multi-frequency bands may be flexibility turned on or turned off avoiding the interference with the WLAN 802.11a during the indoor UWB operation. In addition, the MIMO-based multiuser OFDM multiband of UWB communication transceiver system improves the capability of transmitting very-high data rate in a much longer distance than a convention approach does. Moreover, the present invention of the MIMO-based multiuser OFDM multiband of UWB

communication transceiver system has a scalability to transmit and to receive the data rate of 2.770 Gbps by using one of the multi-frequency bands up to the data rate of 11.082 Gbps by using all of the eleven multi-frequency bands.

Thus, there is a continuing need of the MIMO-based multiuser OFDM multiband of UWB communication transceiver system for transmitting a very-high data rate in a greater distance range in an indoor environment.

Summary

In accordance with one aspect, a MIMO-based multiuser OFDM multiband of UWB base station communication transmitter comprises a multiuser encoding and spreading unit, a polyphase-based multiband, an IFFT unit, a filtering and spreading unit, a MIMO-based multiband modulation and multicarrier RF unit, and a multiple antenna unit.

Other aspects are set forth in the accompanying detailed description and claims.

Brief Description of the Drawings

FIG. 1 is a block diagram of showing a MIMO-based multiuser OFDM multiband of UWB communication transceiver system with different users of UWB mobile stations and a single UWB base station according to some embodiments.

FIG. 2 is a block diagram of showing a MIMO-based multiuser OFDM multiband of an UWB base station communication transmitter for employing eleven antennas according to some embodiments.

FIG. 3 is a detailed block diagram of showing a polyphase-based multiband according to some embodiments.

FIG. 4 is a detailed block of showing a 1024-point IFFT of employing 1000 subcarriers and 24 NULLs according to some embodiments.

FIG. 5 is a detailed block diagram of showing a filtering and spreading section according to some embodiments.

FIG. 6 is a detailed block diagram of showing a MIMO-based multiband modulation and multicarrier RF section according to some embodiments.

FIG. 7 is a frequency spectrum output of the MIMO-based multiuser OFDM multiband of the UWB base station communication transmitter for the indoor operation according to one embodiment.

FIG. 8 is a block diagram of showing a MIMO-based OFDM multiband of an UWB mobile communication receiver for a single user according to some embodiments.

FIG. 9 is a detailed block diagram of showing a two-antenna multiband RF receiver unit according to some embodiments.

FIG. 10 is a detailed block diagram of showing a combination subsection including a set of A/D converters, a set of digital receiver filters, and a set of multiband spreading.

FIG. 11 is a detailed block diagram of showing a combination subsection including a fast Fourier transform (FFT) and frequency-domain equalizers (FEQ) according to some embodiments.

FIG. 12 is a detailed block diagram of showing a polyphase-based demultiband according to some embodiments.

FIG. 13 is a detailed block diagram of showing a despreading, deinterleaver, and decoding unit for a single user of the UWB mobile communication receiver according to some embodiments.

Detailed Description

Some embodiments described herein are directed to the MIMO-based multiuser OFDM multiband of the UWB communication transceiver system for the indoor UWB operation. The MIMO-based multiuser OFDM multiband of the UWB communication transceiver system may be implemented in hardware, such as in an Application Specific Integrated Circuits (ASIC), digital signal processor, field programmable gate array (FPGA), software, or a combination of hardware and software.

MIMO-Based Multiuser OFDM multiband UWB System

A MIMO-based multiuser OFDM multiband of the UWB communication system 100 for the indoor UWB operation is illustrated in FIG. 1 in accordance with one embodiment of the present invention. UWB mobile stations of 110a to 110p can communicate with a MIMO UWB base station 140 to transmit and to receive information data through MIMO-based multi-frequency bands in an indoor environment simultaneously. The UWB mobile station 110a transmits and receives the information data through its two antennas of $120a_1$ and $120a_2$ into air, and communicates with the MIMO UWB base station 140 through its eleven antennas of 130a to 130k. In a similar way, other UWB mobile stations of 110b to 110p also transmit and receive the information data through their antennas of $120b_1$ and $120b_2$ to $120p_1$ and $120p_2$, respectively, and communicate with the MIMO UWB base station 140 through the antennas of 130a to 130k as well. The MIMO UWB base station 140 is coupled to an UWB network interface section 150 in which is connected with an UWB network 160.

Each of the UWB mobile stations of 110a to 110p uses a unique PN sequence to spread and despread a user source signal. The MIMO UWB base station 140 with knowing all of the PN sequences of the UWB mobile stations of 110a to 110p can transmit and receive all of the information data from all of the UWB mobile stations of 110a to 110p based on

MIMO-based OFDM multiband solution by spreading and despreading of the user PN sequences. The MIMO-based OFDM multiband of the UWB communication system uses one of modulations, BPSK, QPSK or 16-QAM, and multicarrier within each of the multi-frequency bands to transmit and to receive the information data rate of 2.770 Gbps on one frequency band up to the information data rate of 11.082 Gbps on eleven frequency bands. As a result, the disclosed MIMO-based multiuser OFDM multiband of the UWB communication system 100 can simultaneously transmit and/or receive the maximum data rate up to 11.082 Gbps by using all of the eleven frequency bands, with an enhancement of transmitting in a longer distance.

MIMO-Based UWB Base Station Transmitter Architecture

FIG. 2 is a block diagram of showing the MIMO-based multiuser OFDM multiband of UWB base station transmitter architecture 200 for the indoor UWB operation according to some embodiments. There are a number of *p* users with a user-1 bitstream 210a to a user-*p* bitstream 210p, respectively. The user-1 bitstream 210a is coupled to a 1/2-rate convolution encoder 212a in which is connected to an interleaver 214a. Using a unique PN sequence of a user-1 key 218a spreads the output sequence of the interleaver 214a. In a similar way, the user-*p* bitstream 210p is coupled to the 1/2-rate convolution encoder 212p that is

connected to the interleaver 214p. Using the unique PN sequence of the user-p key 218p spreads the output sequences of the interleaver 214p. All of the PN sequences of the user-1 key 218a to the user-*p* key 218p are orthogonal each other. This means that a cross-correlation between one PN sequence and other PN sequences is almost zero, while a self-correlation of a user PN sequence is almost equal to one. Then, the *p* output sequences from the interleaver 214a to the interleaver 214p in a parallel operation are added together to form a serial sequence output by using a sum over block duration 220. The serial output of the sum over block duration 220 is converted into eleven parallel sequences by using a polyphase-based multiband 230. Thus, the first of the output sequence from the polyphase-based multiband 230 is converted into a 512-parallel sequence by using an S/P 240a. The 512-parallel sequence is formed to 512-parallel complex sequence with symmetric conjugate. The 512-parallel complex sequence is passed through an IFFT 242a to produce a 1024-parallel real sequence. The IFFT 242a is coupled to a guard 244a to insert 256 samples as a guard interval for the output sequence of the IFFT 242a. As a result, the output of the guard 244a is a 1280-parallel real sequence. Then, the 1280-parallel real sequences are passed through a filtering and spreading section 246a to produce even and odd modulated signal sequences. Carriers multiply the even and

odd modulated signal sequence outputs of the filtering and spreading section 246a by using a MIMO-based multiband modulation and multicarrier RF section 250. In the same way, the eleventh of the output sequence from the polyphase-based multiband 230 is converted into a 512-parallel sequence by using an S/P 240k. The 512-parallel sequence is formed to 512-parallel complex sequence with symmetric conjugate. The 512-parallel complex sequence is passed through an IFFT 242k to produce a 1024-parallel real sequence. The IFFT 242k is coupled to a guard 244k to insert 256 samples as a guard interval for the output sequence of the IFFT 242k. Thus, the output of the guard 244k is a 1280-parallel real sequence. The guard interval is used to avoid an intersymbol interference (ISI) between IFFT frames. Then, the 1280-parallel real sequences are passed through a filtering and spreading section 246k to produce even and odd modulated signal sequences. Carriers multiply the even and odd modulated signal sequences of the filtering and spreading section 246k by using the MIMO-based multiband modulation and RF multicarrier 250. Finally, the eleven output signals of the MIMO-based multiband modulation and RF multicarrier 250 are added together to form a new eleven signals in parallel, and passed through their power amplifiers and multiple antennas of 260a to 260k into air.

Referring to FIG. 3 is a detailed block diagram 300 of showing the polyphase-based multiband 230 according to some embodiments. The polyphase-base multiband 230 includes a RAM memory bank 310 of storing a serial input data, and eleven RAM memory banks of 320a to 320k of storing parallel data. The serial input sequence with a length of N data in the RAM memory bank 310 is divided into eleven parallel sequences with a length of N/11 data by mapping each data of the serial input sequences in the RAM memory bank 310 into eleven RAM memory banks of 320a to 320k. The number size of data in each of the RAM memory banks of 310 and 320a to 320k may be programmed depending on the block size as required by the MIMO UWB communication system.

Referring to FIG. 4 is a detailed block diagram 400 of showing the 1024-point IFFT 410 according to some embodiments. There are 24 Nulls including #0 (DC), and #501 to #523. The values of the input #0 (DC) and #501 to #523 are set to zero. The coefficients of 1 to 500 are mapped to the same numbered IFFT inputs #1 to #500, while the coefficients of 500 to 1 are passed through a complex conjugate 420 and also copied into IFFT inputs of #524 to #1023 to form a complex sequence. Thus, there are a total of 1000 subcarriers for transmitting data and pilot information. In order to make a coherent detection robust against frequency offsets and phase noise, eight of the 1000 subcarriers are dedicated to pilot signals that are

assigned into the subcarriers of #100, #200, #300, #400, and #624, #724, #824, and #924. These pilots are BPSK modulated by a pseudo binary sequence to prevent a generation of spectral lines. In this case, other 992 subcarriers of each OFDM are dedicated to assign for transmitting data information. After performing an IFFT, an output of the 1024-point IFFT is cyclically extended to a desired length in each of the multiband.

The following table 2 lists data rate-dependent parameters of the 1024-point IFFT operation for the multi-frequency bands:

Table 2

Eleven band frequency data rate (Gbits/s)	One frequency band data rate (Mbits/s)	Modulation	Coding rate	Coded bits per sub-carrier	Coded bits per OFDM symbol	Data bits per OFDM symbol
2.770	251.866	BPSK	1/2	1	991.999	495.999
5.541	503.732	QPSK	1/2	2	1983.998	991.999
11.082	1007.464	16-QAM	1/2	4	3967.997	1983.998

Table 3 lists the 1024-point IFFT of detailed timing-related parameters for each of the multi-frequency bands:

Table 3

Parameters	Descriptions	Value
N_{ds}	Number of data subcarriers	992
N_{ps}	Number of pilot subcarriers	8
N_{ts}	Number of total subcarriers	1000
D_{fs}	Frequency spacing for subcarrier (650MHz/1024)	0.6347 MHz
T_{FFT}	IFFT/FFT period (1/ D_{fs})	1.5755 μs
T_{gd}	Guard duration (T_{FFT}/4)	0.3938 μs
T_{signal}	Duration of the signal BPSK-OFDM symbol (T_{FFT} + T_{gd})	1.9693 μs
T_{sym}	Symbol interval (T_{FFT} + T_{gd})	1.9693 μs
T_{short}	Short duration of training sequence ($10 \times T_{FFT}/4$)	3.938 μs
T_{gd2}	Training symbol guard duration (T_{FFT}/2)	0.7877 μs
T_{long}	Long duration of training sequence ($2 \times T_{FFT} + T_{gd2}$)	3.938 μs
$T_{preamble}$	Physical layer convergence procedure preamble duration (T_{short} + T_{long})	7.876 μs

FIG. 5 is a detailed block diagram 500 of showing the filtering and spreading section 246 according to some embodiments. A switch unit 510 including two switches of 520a and 520b is used to split a 1280-parallel data sequences into two parallel data sequences with an even and an odd number, respectively. The switch 520a rotates to the even number of data (for example, b_2, b_4, b_6, …) to form a serial even data sequence, and the switch 520b rotates to

the odd number of data (for example, b_1, b_3, b_5, …) to form a serial odd data sequence. The output sequences of the switches 520a and 520b are spread with a multiband spreading 524 by using two exclusive OR (XOR) of 522a and 522b, respectively. Using a transmitter shaped filter 540a to shape the transmitter spectrum and limit the frequency band filters the serial output sequence of the XOR 522a. The output of the transmitter shaped filter 540a is passed through a D/A converter 550a in which is coupled to an analog reconstruction-filter 560a. The analog reconstruction-filter 560a does a smooth of signal of the D/A converter 550a output. In the same way, using a transmitter shaped filter 540b to shape the transmitter spectrum and limit the frequency band filters the output of the serial output sequence of the XOR 522b. The output of the transmitter shaped filter 540b is passed through a D/A converter 550b in which is coupled to an analog reconstruction-filter 560b. The analog reconstruction-filter 560b does smooth of the output signal of the D/A converter 550b.

Referring to FIG. 6 is a detailed block diagram 600 of showing the MIMO-based multiband modulation and multicarrier RF section 250 according to some embodiments. Analog output signals of the filtering and spreading of 246a to 246k as shown in FIG. 2 in parallel are passed through eleven multiband modulations of 610a to 610k. All

of the multiband modulations of 610a to 610k are equivalent. The multiband modulations of 610a to 610k may be one of modulations including BPSK, QPSK, or 16-QAM. The output signals of the multiband modulations of 610a to 610k are coherently added together by using eleven sum units of 620a to 620k. Then, the outputs of eleven sum units of 620a to 620k are in parallel passed through eleven analog bandpass filters of 630a to 630k to produce bandlimited signals for multiple antennas transmitter.

Spectrums of MIMO-Based UWB Base Station Transmitter

FIG. 7 is an output frequency spectrum 700 of the MIMO-based multiuser OFDM multiband of the UWB base station communication transmitter, including eleven multi-frequency band spectrums of 720A to 720K according to some embodiments. A FCC emission limitation 710 for the indoor UWB operation is also shown in FIG. 7. Each transmitter frequency bandwidth of the eleven multi-frequency band spectrums of 720A to 720K is 650 MHz and is fitted under the indoor FCC emission limitation 710 with different carrier frequencies. The detail positions of each transmitter multi-frequency band spectrums (dBm) along with the center, lower and upper frequencies (GHz) as well as the channel frequency bandwidth (MHz) are listed in Table 4:

Table 4

Multichannel Label	Center Frequency (GHz)	Lower Frequency (GHz)	Upper Frequency (GHz)	Frequency Bandwidth (MHz)
720A	3.45	3.125	3.775	650
720B	4.10	3.775	4.425	650
720C	4.75	4.425	5.075	650
720D	5.40	5.075	5.725	650
720E	6.05	5.725	6.375	650
720F	6.70	6.375	7.025	650
720G	7.35	7.025	7.675	650
720H	8.00	7.675	8.325	650
720I	8.65	8.325	8.975	650
720J	9.30	8.975	9.625	650
720K	9.95	9.625	10.275	650

During the indoor UWB operation, the fourth and/or fifth multi-frequency bands of the MIMO-based multiuser OFDM multiband of the UWB base station transmitters can be turned off in order to avoid an interference with WLAN 802.11a lower U-NII frequency band and/or upper U-NII frequency band. In some cases, the MIMO multiuser OFDM multiband of the UWB base station and mobile transmitters can turn off some subcarriers within the OFDM in the fourth and/or fifth multi-frequency bands if the WLAN 802.11a system only uses certain subchannels in the lower U-NII or in the upper U-NII frequency bands.

MIMO-Based UWB Mobile Receiver Architecture

FIG. 8 is a block diagram of showing a MIMO-based OFDM multiband of UWB mobile communication receiver 800 for the indoor UWB operation according to some embodiments. A two-antenna based multiband RF receiver unit 810, which is coupled to an A/D unit 822, receives the MIMO-based multiuser OFDM multiband of UWB signals from two antennas 808a and 808b. The eleven bandlimited MIMO-based multiuser OFDM multiband of UWB analog signal outputs of the two-antenna based multiband RF receiver unit 810 are in parallel sampled and quantized by using an A/D converter unit 822, with the sampling frequency rate at 720 MHz. Using a digital receiver filter unit 824 to remove out of band signals filters the digital signals of output of the A/D converter unit 822. Then the outputs of digital receiver filter unit 824 despread with a despreading sequence of a multiband-despreading unit 826. The output digital signals of the multiband-despreading unit 826 are passed through time-domain equalizers (TEQ) 828. The TEQ 828 is used to reduce the length of cyclic prefix to a more manageable number without reducing performance significantly. In other words, the TEQ 828 can produce a new target channel with a much smaller effective constraint length when concatenated with the channel. Thus, the outputs of the TEQ 828 in parallel are passed through a set of S/Ps of 830a to 830k to produce parallel digital

sequences. Each of the S/Ps of 830a to 830k produces 1280 parallel digital sequences for each of guard removing units of 832a to 832k. The guard removing units of 832a to 832k remove 256 samples from the 1280 parallel digital sequences of the S/Ps of 830a to 830k to produce 1024 parallel digital sequences, which are used as inputs for FFT units of 834a to 834k. Each of the FFT units of 834a to 834k produces 512 frequency-domain signals that are used for frequency-domain equalizer (FEQ) units of 836a to 836k. The FEQ units of 836a to 836k are used to compensate for phase distortions, which are a result of phase offsets between the sampling clocks in the transmitter and the receiver of the MIMO-based multiuser OFDM multiband of the UWB communication transceiver. This is because the phases of the received outputs of the multiband FFT units of 834a to 834k are unlikely to be exactly the same as the phases of the transmitter symbols at the input to the IFFT units of 242a to 242k of the MIMO-based multiuser OFDM multiband of UWB base station transmitter as shown in FIG. 2. Thus, the outputs of the FEQ units of 836a to 836k are passed through a set of P/S units of 838a to 838k to produce a serial sequence for all of the eleven multi-frequency bands. All of the serial sequences from the P/S units of 838a to 838k, with each sequence length of N, are added together to produce a sequence length of 11N by using a polyphase-based demultiband 840. The output sequence of the polyphase-based

demultiband 840 is passed through a despreading, deinterleaver, and decoding unit 850. The despreading, deinterleaver, and decoding unit 850 perform despreading, deinterleaving and decoding for the MIMO-based multiuser OFDM multiband of the UWB mobile communication receiver.

Referring to FIG. 9 is a detailed block diagram 900 of showing the two-antenna based multiband RF section receiver section 810 according to some embodiments. The outputs of the two-antenna 808a and 808b in FIG. 8 are in parallel passed into two low noise amplifiers (LNA) of 910a and 910b, which are coupled to two automatic gain controls (AGC) of 920a and 920b. The outputs of the AGCs 920a and 920b are passed through two analog bandpass filters of 930a and 930b to produce two output signals that are added together by using a sum over block duration 940. Then, an output signal of the sum over block duration 940 is in parallel passed into eleven-multiband down converters and demodulations of 950a to 950k. Each of the multiband down converters and demodulations of 950a to 950k produces two output signals.

Referring to FIG. 10 is a detailed block diagram 1000 of showing one combination section 820 according to some embodiments. This combination section 820 includes twenty-two A/D converters of $1010a_1$ and $1010a_2$ to $1010k_1$ and $1010k_2$, twenty-two digital receiver filters of $1020a_1$ and $1020a_2$ to $1020k_1$ and $1020k_2$, and twenty-two XOR of $1030a_1$ and $1030a_2$ to

$1030k_1$ and $1030k_2$, and eleven multiband despreading of 1040a to 1040k. The outputs of the multiband down converters and demodulations of 950a to 950k in FIG. 9 are in parallel passed through the twenty-two A/D converters of $1010a_1$ and $1010a_2$ to $1010k_1$ and $1010k_2$ to produce the quantized digital signals. All of the A/D converters of $1010a_1$ and $1010a_2$ to $1010k_1$ and $1010k_2$ use the same bit resolution and the same sampling frequency rate. The A/D converters of $1010a_1$ and $1010a_2$ to $1010k_1$ and $1010k_2$ are coupled to the twenty-two digital receiver filters of $1020a_1$ and $1020a_2$ to $1020k_1$ and $1020k_2$, respectively. All of the twenty-two digital receiver filters of $1020a_1$ and $1020a_2$ to $1020k_1$ and $1020k_2$ filter out of unwanted digital signals from the outputs of the twenty-two A/D converters of $1010a_1$ and $1010a_2$ to $1010k_1$ and $1010k_2$, respectively. All of the twenty-two digital receiver filters of $1020a_1$ and $1020a_2$ to $1020k_1$ and $1020k_2$ are equivalent in which contain the same filter attenuations and the filter bandwidths with the same filter coefficients and a linear phase. The outputs of the twenty-two digital receiver filters of $1020a_1$ and $1020a_2$ to $1020k_1$ and $1020k_2$ are despread with the output sequences of the eleven multiband despreading of 1040a to 1040k, respectively, by using the twenty-two XOR of $1030a_1$ and $1030a_2$ to $1030k_1$ and $1030k_2$, respectively. All of the output sequences of the eleven multiband despreading of 1040a to 1040k are orthogonal each other.

FIG. 11 is a detailed block diagram 1100 of showing a combination subsection including the FFT 834 and the FEQ 836 according some embodiments. The FFT 834 has a 1024-point input of real-value and produces a 512-point complex data with labels of 0 to 511, while a 512-point complex data with labels of 511 to 1023 is disable. The FFT 834 with labels of 0 to 511 also contains 12 Nulls. So, the FFT 834 produces a 500-point complex data for the FEQ 836. The FEQ 836 contains 500 equalizers of $1110a_1$ to $1110a_{500}$, 500 decision detectors of $1120a_1$ to $1120a_{500}$, and 500 subtractions of $1130a_1$ to $1130a_{500}$ that operate in parallel. Each of the equalizers of $1110a_1$ to $1110a_{500}$ has N-tap with adaptive capability. Each of the decision detectors of $1120a_1$ to $1120a_{500}$ is a multi-level threshold decision. Each of the subtractions of $1130a_1$ to $1130a_{500}$ performs subtracting between the output of each of the equalizers of $1110a_1$ to $1110a_{500}$ and the output of each of the decision detectors of $1120a_1$ to $1120a_{500}$. The output of each of the subtraction of $1130a_1$ to $1130a_{500}$ is referred to an error signal, which is used to adjust the N-tap coefficients of the each of the equalizers of $1110a_1$ to $1110a_{500}$ by using an adaptive algorithm 1130.

The phases of the received outputs of the FFT 834 do not have exactly the same as the phases of the transmitter symbols at the input to the IFFT units of 242a to 242k of the MIMO-based multiuser OFDM multiband of UWB base station

transmitter as shown in FIG. 2. In addition, the phase responses have to consider the channel in which is coped with the TEQ 828 as shown in FIG. 8. Thus, the FEQ 836 in FIG. 11 is used to compensate for the phase distortion that is a result of a phase offset between the sampling clocks in the transmitter and the receiver of the MIMO-based multiuser OFDM multiband of the UWB communication transceiver. The FEQ 836 also offers the additional benefit of received signal scaling before decoding since the FEQ 836 can be used to adjust the gain of the FFT 834 output so that the decision detectors of $1120a_1$ to $1120a_{500}$ can be set the same parameters for all subchannels regardless of the different subchannel attenuations.

FIG. 12 is a detailed block diagram 1200 of showing a polyphase-based demultiband 840 according to some embodiments. The polyphase-base demultiband 840 includes eleven RAM memory banks of 1210a to 1210k of storing parallel data, and one RAM memory bank of 1220 of storing a serial data. The size of RAM memory banks of 1210a to 1210k and 1220 can be programmed. At a time unit, one of bit data from all of the eleven RAM banks of 1210a to 1210k is in parallel shifted into the RAM bank of 1220. The RAM memory bank of 1220 then shifts out all the bit data. The above procedure is repeated until finishing all the bit data in the RAM memory banks of 1210a to 1210k.

Referring to FIG. 13 is a detailed block diagram 1300 of showing the despreading, deinterleaver, and decoding unit 850 according to some embodiments. This unit 850 includes a despreading 1310, a user-*i* key 1320, a deinterleaver 1330, a Viterbi decoding 1340, and a user-*i* bitstream 1350. The output sequence of the polyphase-based demultiband 840 in FIG. 8 is despread with a spreading sequence of the user-i key 1320, which provides a unique key sequence, by using the despreading 1310. The despreading 1310 is a XOR operation to produce an encoded user-*i* data bitstream. This encoded user-*i* data bitstream is then deinterleaved by using the deinterleaver 1330 that is also coupled to the Viterbi decoding 1340. The Viterbi decoding 1340 decodes the encoded user-*i* data bitstream to produce an original transmitted user-*i* data bitstream that is stored into the user-*i* bitstream 1350.

While the present inventions have been described with respect to a limited number of embodiments, those skilled in the art will appreciate numerous modifications and variations therefrom. It is intended that the appended claims cover all such modifications and variations as fall within the true spirit and scope of these present inventions.

What is claimed is: